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14. ABSTRACT

We describe a network of diverse sensors and methods for capability discovery and resource aggregation. Camera nodes utilize the distributed sensors for selective image acquisition and processing. Compared to standalone cameras, these networked sensors consume less power and can be adjusted to heterogeneous and situation-specific resolutions by spreading them thinner or denser. Most importantly, however, diverse sensors can exploit a wider range of the electromagnetic spectrum. In field tests, our system behaved well above our expectations both in terms of detecting all events of interest as well as capturing images of interest.

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Resource Aggregation in Smart Sensor Systems

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We describe a network of diverse sensors and methods for capability discovery and resource aggregation. Camera nodes utilize the distributed sensors for selective image acquisition and processing. Compared to standalone cameras, these networked sensors consume less power and can be adjusted to heterogeneous and situation-specific resolutions by spreading them thinner or denser. Most importantly, however, diverse sensors can exploit a wider range of the electromagnetic spectrum. In field tests, our system behaved well above our expectations both in terms of detecting all events of interest as well as capturing images of interest.

General Terms
Capability Discovery, Resource Aggregation, Surveillance, Sensor System. Smart Camera, Sensor Fusion, Roadside Surveillance.

Keywords
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1. INTRODUCTION
Wireless sensor networks are an efficient and cost-effective technology to implement a variety of surveillance and security applications (Akyildiz et al, 2002; Chong & Kumar, 2003). Small, cheap, low-power sensors can be networked together to form an unattended and autonomous sensor system that can, for instance, monitor a public area for suspicious behavior of people and vehicles traversing it (see also Rinner et al., 2006). Sensors for specific bands of the electromagnetic spectrum can be placed optimally according to their characteristics and to the particular situation and topology. For example, fog-penetrating infrared sensors can be placed at a further distance providing larger coverage, whereas visible-light sensors and sound detectors are more useful at a closer range. More powerful "aggregator" nodes can collect the data generated by the sensor network, analyze them for characteristics such as suspiciousness and report to human security personnel for further action those activities exceeding a threshold.

We have developed a sensor network for remote area surveillance of both vehicles and people. This sensor network uses a combination of several different types of sensors and networking technologies, including PIR (passive infrared), magnetometers and imaging devices as sensors and 802.15.4/ZigBee, 802.11b and satellite phones for communication.

Our system employs Crossbow's MSP-SYS410CA platform (Crossbow, 2005) for implementing distributed object detection and motion estimation, and the TinyOS operating system (Hill et al, 2000) for the sensor nodes. Sensor data is collected at an aggregator node which is equipped with a digital photo camera, a satellite phone connection, and a WiFi connection. Upon detecting an interesting object/event, the network triggers the camera to capture a number of photos which are uploaded via satellite phone to a remote control center.

2. SYSTEM ARCHITECTURE
The complete experimental system comprises a collection of self-contained, stand-alone sensor networks. As shown in Figure 1, each sensor network consists of a number of wireless nodes, a base station and a general purpose aggregator node (PC) with camera and satellite phone. The sensor nodes form a 802.15.4 network to transfer data to the base station, which in turn transfers the data over a serial port to the PC for aggregation and analysis. Depending on the results of the analysis, the computer triggers the camera to take a variable number of photos. In our current implementation, we transmit these pictures to the control station using a satellite phone. The event

detection algorithms within such a sensor network are specific to a sensor topology alongside a road.

be willing to share resources. If two subnets, for example, had their own images to upload, they may decide not to

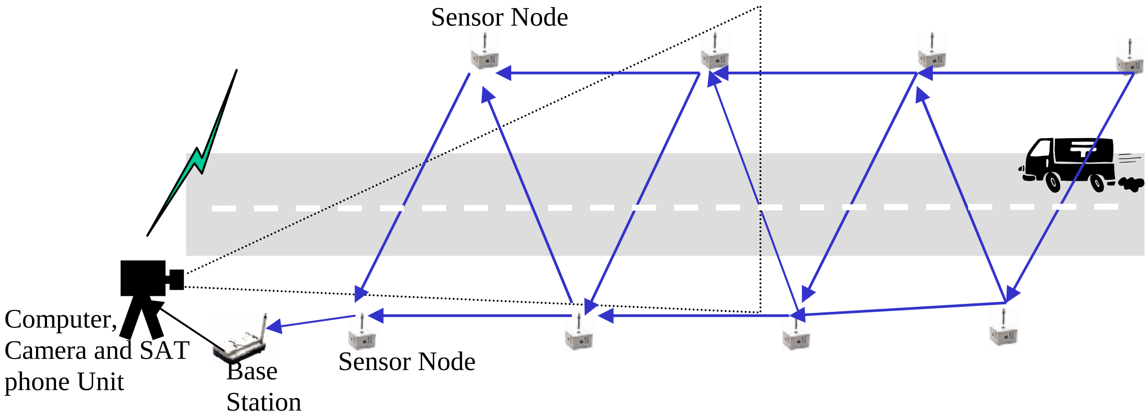

Figure 1. A self-contained sensor network

Aside from being scalable in the number of nodes per network, our system is also scalable in that a collection of these independent networks (called subnets from here on) can be joined together to provide surveillance along multiple dimensions as shown in Figure 2. The subnets are connected via 802.11b wireless links in the aggregator PCs. Such a network of subnets can provide coverage in multiple directions, for example, along multiple roads.

We will now describe how we addressed the bandwidth and power constraints of satellite phones with capability discovery methods and resource aggregation schemes among such a network of subnets.

Using the discovery mechanism, the subnets automatically inquire about the capabilities of neighboring subnets. Once their capabilities are known, desired resources can be aggregated for better performance. For example, if one of the subnets has a large number of images to be uploaded, it can ask the neighboring subnets to help upload the pictures, provided they have the capability and are willing to share their network resource. Individual subnets may or may not collaborate. Capability discovery has been implemented using the ad-hoc 802.11b technology.

3. RESULTS

We field-tested our network of networks in the NPS TNT (Tactical Network Topology) experiments. TNT is a large-scale, prototype-grade test environment which simulates as closely as possible the surveillance conditions in a real environment. All vehicles and “actors” perform real-world actions as they can be expected in friendly and hostile environments. Our system was able to detect *all* vehicles and people successfully, without any false positives. Also, it accurately estimated vehicle speed (up to 40mph) based on the distributed sensors’ binary data (present/absent). For each detection, the system performed as designed and captured a number of images and send them to our control station.

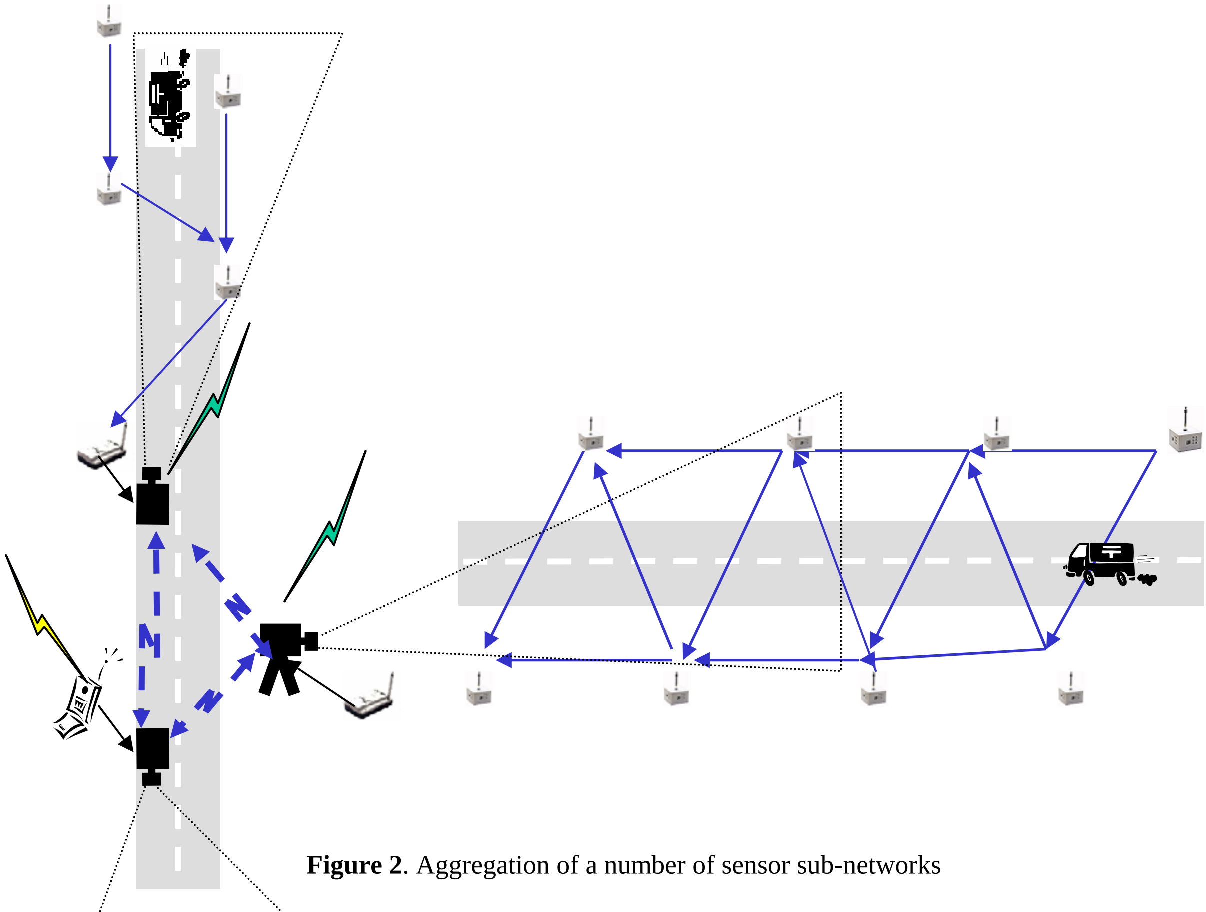

Figure 2. Aggregation of a number of sensor sub-networks

4. FUTURE WORK

We are extending and improving our system in a number of ways. One extension links the ground-based sensor surveillance system with various Unmanned Aerial Vehicles (UAVs). These UAVs are equipped with video cameras and transmit live video to a ground station. The advantage of such a system is that it provides an alternate view of the terrain – ground-based cameras provide the front view and the UAV camera provides a birds-eye view of the situation. An early implementation of this system has already been completed (Schall, 2006) and is currently being tested. We are now investigating the issues of calculating the UAV's flight path so that it will provide a meaningful view and coverage of the area.

We are also implementing video processing methods on each network's computational unit in the style of smart cameras (see, for example, Wolf et al., 2002). Rather than sending uncompressed video to the control system (bandwidth and power limitations), only those parts of the image where an object has been detected will be transmitted, possibly after compression and along with higher-level information. One of the areas of investigation is automatic object recognition based on the multimodal information available: the electromagnetic signals as captured by the diverse set of sensors including the camera, and the spatial trail through the area over time.

5. REFERENCES

[1] Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E., "Wireless Sensor Networks: A Survey,"*Computer Networks*, Vol. 38, 393-422, 2002.

[2] Bramberger, M., Doblander, A., Maier, A., Rinner, B., and Schwabach, H. "Distributed Embedded Smart Cameras for Surveillance Applications." IEEE Computer 39(2) pages 68-75, February 2006.

[3] Chong, C.-Y., & Kumar, S. P., "Sensor Networks: Evolution, Opportunities, and Challenges," *Proceedings of the IEEE*, Vol. 91, No. 8, 1247-1256, August 2003.

[4] Crossbow. Press Release, available (as of 11 August 2006) at http://www.xbow.com/ General_info/Info_pdf_files/XMesh_MOTEVIEW_PR.pdf, March 2, 2005.

[5] Schall, S. "Path Calculation and Packet Translation for UAV Surveillance in Support of Wireless Sensor Networks". *M.Sc. Dissertation, Naval Postgraduate School, Monterey, CA, 2006* (in progress).

[6] Wolf, W, Ozer, B., and Lv, T., "Smart cameras as embedded systems," IEEE Computer, 35(9) September 2002, pp. 48-53.